

Title: Three-dimensional analysis of a lofted instep kick by male and female footballers

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Abstract

There is a paucity of data describing the lofted instep kick, and little information on the kinematic differences between male and female footballers. This study provides a preliminary investigation into the differences in motion patterns between the sexes. A four camera motion analysis system videoed thirteen amateur footballers (seven female, six male) attempting a standardised task that represented a lofted instep kick of approximately 35 m. Footballers performed twenty kicks, with the three trials categorised closest to the standardised distance retained for statistical analysis. Three-dimensional motion patterns for kicks of 35 m illustrated that female footballers produced greater fluctuation in movement patterns for pelvic, hip joint and thoracolumbar spine motion in the frontal plane; thorax and hip joint transverse rotation; and ankle dorsiflexion / plantarflexion motion. Peak hip extension ($P = 0.018$), impact hip abduction ($P = 0.032$), impact ankle plantar flexion ($P = 0.030$) and resultant ball velocity ($P = 0.004$) differed significantly between sexes. Principle Component Analysis highlighted associations between kinematic variables related to ball velocity and sex including a reduced hip abduction and increased internal rotation approaching impact, and greater peak knee flexion, respectively. In summary, increased variation in direction of segment motion, increased backswing and formation of a tension arc by females compared to males, may be related to anthropometric, strength and muscle activation differences. Specifically this exploratory study indicates future research would benefit from exploring trunk, pelvis and hip kinematics and kinetics, and whether training the trunk, pelvis and hip musculature assists female footballers.

Key words: hip, kinematics, football, soccer, thoracolumbar spine

Introduction

Differences between men and women's football have been noted in terms of strategies and styles of play which may be attributed to the female footballers being less capable of performing a long, lofted kick (Scott, 1999). Although this potential difference in lofted instep kicking exists, there is a paucity of research on three dimensional kinematics of the kick for either sex, therefore initial descriptive and cross sectional studies are required to serve as a guide for future research in the area (Bishop, 2008).

Kinematic differences between the sexes during maximal instep kicking have included less effective use of the tension arc (Shan, 2009) by skilled female players. The formation of a tension arc involves over extension of the kick side hip, trunk rotation towards the non-kick side and over-extension and abduction of the arm on the non-kick side at the beginning of the kick, which is released approaching foot-ball impact (Shan & Westerhoff, 2005). Whether the tension arc is a characteristic of lofted instep kicking or used to a lesser or greater extent by either sex has not been previously reported. Exploration of the movement characteristics of the trunk, hip and pelvis in female footballers is required to understand this motion and the implications for a lofted instep kick.

Historically coaching practice advocates a backward leaning trunk at impact for a lofted instep kick (Hargreaves, 1990; Hughes, 1994) and this continues to be used (CoachesColleague, 2009). Research on trunk inclination for instep kicking has reported differing degrees of backward lean between two professional players (Lees & Nolan, 2002) and for male and female players (Orloff et al., 2008), indicating that clarification of trunk inclination for lofted instep kicking is required. The lack of consensus in existing literature and the scarcity of research on the three-dimensional motion of the lofted instep kick highlight the need for more studies in this area, especially the need to explore trunk and hip motion.

The aim of the study was to investigate differences in joint angular displacement, ball and foot velocity between males and females performing a standardised lofted instep kick. It was hypothesised that differences in hip and trunk joint angular displacement would be evident between sexes performing a standardised lofted instep kicking task, and males would display a greater ball velocity at impact. In addition the three-dimensional motion of male and female footballers performing a 35m plus lofted instep kick was quantified and described.

Methods

Seven female (age: 25.3 ± 7.6 y, height: 164.8 ± 4.8 cm, body mass: 68.5 ± 9.7 kg) and six male (age: 22.3 ± 3.4 y, height: 182.0 ± 4.0 cm, body mass: 81.9 ± 10.8 kg) experienced amateur football players volunteered for the study. All participants were currently playing in the top divisions of the regional football league where the study took place, and skilled in the ability to perform a lofted instep kick. Ethical clearance was granted by the institutions human research ethics committee and all participants gave their written informed consent. Participants attended familiarisation sessions prior to testing, within the sports hall testing location.

Anthropometry

Anthropometry protocols, followed guidelines supported by the International Society for the Advancement of Kinanthropometry (ISAK) (Norton & Olds, 1996). Anatomical landmarks were located and marked using a fibre tip pen with all measurements taken to the nearest 0.1 cm using large sliding calipers from a Harpenden Anthropometer Measuring Set (Holtain Ltd, Crosswell, UK). Each variable was measured in turn with results being recorded by an assistant and repeated back to the tester for clarification, these measurements were then repeated twice more. The median value for each variable was reported.

Measurements recorded were thigh (trochanterion: the most superior point on the greater trochanter to tibiale laterale: most superior point on lateral border of head of tibia), tibiale

laterale height (tibiale laterale to floor), tibia (tibiale mediale: most superior point on the medial border of the head of the tibia to sphyrion tibiale: most distal tip of the medial malleolus of the tibia), foot (most posterior point of calcaneus to anterior portion of first distal phalanx), pelvis (biiliocristale breadth: distance between left and right iliocristale - most lateral aspect of iliac crest on a line drawn vertically from the middle of the armpit) and bitrochanteric breadth (Norton & Olds, 1996). Test-retest reliability of five participants indicated excellent agreement across tests, the greatest standard error of the measurement observed for the thigh (1.4cm, ICC 0.94), whilst the remaining variables ranged from 0.1 – 0.9cm (ICC 0.96 to 1.00).

Protocol

All participants carried out a standardised 15 minute warm-up that comprised of phases of jogging and running based activities interspersed with static and dynamic stretching. The duration and intensity of activities increased each phase. Markers were attached to the 4th and 10th thoracic vertebrae spinous process, the angle of the 8th rib on the left and right, the posterior superior illiac spines, sacrum (S₄ spinous process), greater trochanter of the femur, lateral femoral epicondyle, mid-thigh 10 cm vertically above the patella base, the right lateral malleolus of the fibula and on the subjects' footwear directly over the 5th metatarsal head to define the thorax, pelvis, thigh, knee and foot segments (Gilleard, Crosbie, & Smith, 2002). Following a demonstration, participants carried out five practice kicks. Participants were videoed in standing neutral posture before a standardised definition of the aims of the task was conveyed. Previous research indicates variability for a maximal instep kick is suitably low over five trials (Lees & Rahnama, 2013) indicating the five practice kicks may have been sufficient to stabilise kinematic performance. However, participants were allowed a further self-selected number of practice trials due the break imposed by the recording of a neutral posture and reading of task definition. The number of practice trials selected was typically twelve. Participants were then

videoed performing 20 trials. No verbal motivation was given however participants were aware of kick distance and accuracy.

The kicking task involved a two-step angled approach of 45-60° towards a stationary football to perform a right-foot lofted instep kick using the dorsal aspect of the foot. Participants kicked a FIFA inspected football (0.44 kg) inflated to 0.7 kg·cm⁻² (FIFA, 2012). Two flat retro reflective markers were affixed to the ball. To perform a realistic lofted instep kick participant's kicked the ball over a 2 m high net, positioned 15 m from the initial ball placement site aiming towards the centre square (1 m x 1 m) of a 3 m x 3 m target, 27.6 m ahead and 1.37 m above floor level (Figure 1). This represented a kick of approximately 35 m. Participants were also made aware that the target was a feature to aim at, with height and distance being the primary objectives of the task rather than accuracy, as accuracy constraints have been shown to have a detrimental effect on the speed of task performance. (Lees & Nolan, 2002).

FIGURE 1 ABOUT HERE

Kinematic data was collected using a gen-locked four camera (Panasonic WV-CL830/G) Peak Motus motion analysis system (50Hz) and Peak Motus v7.0 software (Englewood, CO, USA). Pilot work indicated four cameras were sufficient to ensure all markers were tracked by a minimum of two cameras for the majority of frames, keeping interpolation to a minimum. The motion analysis system-configuration showed excellent test-retest and trial-to-trial reliability, ICC > 0.99, similar to other reports under static conditions (Vander Linden, Carlson, & Hubbard, 1992; Wilson et al., 1999). Trial-to-trial percent close agreement indicated 75 - 100% of values were within 0.3° of agreement, under test-retest conditions 50 - 100% of values were

within 1.2° of agreement and standard error of the measurement was between $0.10 - 0.68^{\circ}$ for all three planes.

Data Processing and Analysis

Only one male participant did not self-report as right-foot dominant, and prior to the decision to include their data in the study, their kinematic profiles were inspected to ensure their data fell within 95% confidence intervals of the remaining male participant's data. Kicks were categorised according to distance, 15-27.6 m, 27.7-34.9 m and 35 m plus (Figure 1). Marker centroids were auto-tracked, raw coordinate-time data for each marker path were scaled, interpolated and filtered using quintic spline processing and a low pass Butterworth filter with optimal filtering, the cut-off level determined by the Jackson Knee Point Method (Jackson, 1979). Segmental coordinate systems were constructed based on the method by Grood and Suntay (1983). All angles were calculated relative to the neutral standing posture. Angular displacement data was time normalised between final toe-off of right foot preceding foot-ball impact and foot-ball impact (total kick time) and ensemble-averaged for each participant. Three-dimensional angular displacement data were reported for the thoracolumbar spine (relative motion between thorax and pelvis) and right hip joints and thoracic, pelvic and right thigh segments. Two-dimensional angular displacement data were reported for the right knee and ankle joints. Peak angular displacements between toe-off (of kicking foot prior to impact) and foot-ball impact, and angular displacements at toe-off, heel-strike (of non-kicking foot prior to impact) and impact for the thoracolumbar spine, hip, knee and ankle joints were further analysed.

Resultant post impact ball velocity was calculated from the first frame where the ball was no longer in contact with the foot and the frame prior to ball release. Pre impact foot velocity was calculated between impact frame and frame prior to impact. Unfiltered horizontal and vertical,

scaled co-ordinates of the ball markers and the 5th metatarsal marker were used to calculate ball and foot velocity respectively. Trial-to-trial and test-retest reliability was determined for all segment and joint angles reported between toe-off of the kicking foot prior to impact and foot-ball impact.

An a priori power analysis conducted using G*Power v3.1.2 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated a minimum total sample size of $n = 2$ to 7 per group was required to achieve a power of > 0.8 for a two-tailed alpha of 0.05, based on combined data from Browder et al. (1991) and, Muewssen and Tant (1992) for hip and knee flexion / extension range of motion. Independent t-tests were used to investigate anthropometric and kinematic differences between sexes ($P < 0.05$). The kinematic data incorporated into the above statistical analysis were the mean angular data for the thoracolumbar spine, hip, knee and ankle joints, and ball and foot velocity, of three trials for the maximum distance kicked, (categorised using the above definitions). To explore an overview of the angular displacement data, a principal component analysis (PCA) with no rotation was conducted. Following inspection of the scree plot the first two principal axes (45.14% σ^2) were extracted. These components were further explored with respect to their correlation with ball parameters and sex. SPSS v19.0 and Excel were used for all statistical procedures.

Results

Male footballers were significantly taller, heavier and had longer limb lengths than their female counterparts (P range < 0.001 to 0.038); however there was no significant difference in biiliocristale breadth ($P = 0.576$). The majority of the kinematic data showed excellent trial-to-trial reliability with ICC > 0.75 (Shrout & Fleiss, 1979) and percent close agreement (5°) 50 - 100%. A few variables demonstrated ICC's < 0.4 (poor) for both sexes and all distances, however, the majority of these also reported a percent close agreement (5°) of between 80 -

100%. The high percent close agreement indicated a small spread of the data, as ICC's are affected by reduced range in the data (Rey, Plapp, Stewart, Richards, & Bashir, 1987) this would account for the low ICC's rather than a high degree of variation in the movement between trials. Test-retest reliability was excellent for the majority of variables (ICC, 0.77 – 0.99) with percent close agreement (5°) ranging from 67 - 100%. In most instances where a lower ICC was reported a small spread of data (percent close agreement (5°) 100%) was apparent, again affecting ICC scores (Rey et al., 1987). Overall the joint displaying the least stability of movement for specific instances was the ankle joint (ICC 0.31 – 0.39, percent close agreement (5°) 33%).

Kinematic descriptions of the temporal characteristics as well as joint and segment motion for kicks of the 35 m plus for male and female players are provided in Supplemental Digital Content 1 (SDC1). Six male and three female footballers successfully performed at least three 35 m plus kicks, whereas four female players recorded at least three maximal distance kicks of up to 27.6 m. Significant differences between sexes were reported for peak hip extension, hip abduction at impact, ankle planter flexion at impact and resultant ball velocity, all displaying a large effect size (Table 1).

TABLE 1 ABOUT HERE

Ordination plots of the first two axes extracted from the PCA were overlaid with ball parameters and sex (Figure 2) and revealed that the first component was weakly related to ball velocity ($r = 0.476$, $P = 0.012$) and the second weakly related to sex ($r = 0.444$, $P = 0.020$). Angular displacement variables and corresponding loadings for the two components extracted from the PCA are provided in Table 2. Variables with loadings $> |0.50|$ were interpreted within each

component. The association of each variable with respect to the component was interpreted according to the direction of the component loading and variable.

FIGURE 2 ABOUT HERE

TABLE 2 ABOUT HERE

Component one indicated that for faster ball velocities, a reduced hip extension and external rotation and an increased thoracolumbar spine external rotation between toe-off and heel-strike was associated with a reduction in hip abduction and increase in internal rotation between heel-strike and impact. Additional associated movement patterns were an increase in peak thoracolumbar spine adduction throughout the kick (toe-off, peak and impact) and an increased thoracolumbar spine extension around heel-strike. Component two describes a reduced ankle plantar flexion throughout the kick, and is associated with greater knee flexion and thoracolumbar spine adduction at heel-strike and a greater peak knee flexion for female footballers.

Discussion

The female footballers had significantly increased peak hip extension just prior to heel-strike (Table 1), suggesting they were aiming to maximise backswing before making ball contact. Similarly larger hip flexion / extension has been reported in skilled compared to novice female footballers for maximal low instep kicking (Shan, Daniels, Wang, Wutzke, & Lemire, 2005). A larger backswing may result in more momentum at time of impact and utilised as a strategy to increase ball velocity at impact. However, a decrease in hip extension in the first part of the kick was associated with faster ball velocities (Table 3), implying that this strategy may not be

optimal. Exploring the contribution of the segments to hip motion in the first half of the kick (SDC1), although the thigh contributed most to increasing hip extension, an increased anterior tilt of the pelvis at this point contributed to an increase in thoracolumbar spine extension, which was associated with an increased ball velocity (Table 2). Anterior tilt to increase the segmental contribution of the pelvis to the end point velocity of the kicking limb at impact is therefore indicated as an alternative strategy to increasing ball velocity.

An increased thoracolumbar spine external rotation (thorax rotating to left, pelvis to right) between toe-off and heel-strike was associated with increased ball velocity. Despite male players having a significantly greater ball velocity there were no significant differences between sexes for thoracolumbar spine external rotation. The motion patterns (SDC1) indicated that for both sexes the thorax was rotated to the right at toe-off. Then male players rotated the thorax to the left the entire kick. However, females displayed a greater initial rotation of the thorax towards the left, but maintained a similar amount of thoracolumbar spine external rotation in the first half of the kick due to a greater amount of pelvis rotation to the right. Increasing transverse rotation of the thorax to the left after toe-off along with the increased hip extension could have been a strategy to increase the pre-stretch of the quadriceps and trunk muscles and form a tension arc to increase kicking power for female footballers, similar to males performing a maximal instep kick (Shan & Westerhoff, 2005).

The release of the tension arc includes rotating the trunk towards the kick side along with a quasi 'whip-like' movement of the kicking leg towards the ball and upper body flexion (Shan & Westerhoff, 2005). The patterns of motion displayed by the female footballers (SDC1) indicated they may have been releasing the tension arc in an attempt to increase ball velocity. Male footballers did not demonstrate the same patterns suggesting they could have achieved enough power in the kick as a result of the anthropometrical differences. The male footballers had a significantly greater body mass indicating a greater lower limb mass and therefore an increased

momentum for a given foot velocity at impact. In addition the significantly longer limbs of male players would potentially increase lever length and hence linear velocity of the foot at impact for similar angular velocities of the kicking limb. Male footballers have previously been reported as having greater toe velocity for low maximal instep kicks (Barfield, Kirkendall, & Yu, 2002). Potential differences may also be related to muscle strength or activation patterns (Brophy et al., 2009, 2010). It is therefore possible male footballers in the current study controlled their kicking motion to the non-maximal task objective.

Reduced hip abduction approaching impact was associated with greater ball velocity suggesting orientating the hip closer to the midline of the body facilitates kick performance, potentially due to less demand on hip joint musculature to stabilise the pelvis and thigh at impact. In the latter part of the kick females tilted the pelvis downwards on the kicking side (SDC1) in contrast to the pelvis motion displayed by male players in the current study and low instep kicking (Levanon & Dapena, 1998). This orientation of the pelvis contributed to the significantly greater hip abduction displayed by females at impact (Table 1) which may have been necessary to position the foot appropriately on the ball at impact. However, this pelvis orientation may be detrimental to their ability to maximise velocity of the kicking foot as it contacts the ball (Lees, Asai, Andersen, Nunome, & Sterzing, 2010) if lever length is reduced.

The PCA indicated that a reduced external hip rotation in the early, and increased internal hip rotation in the latter part of the kick were associated with a greater ball velocity. The reduced external hip rotation may be connected to the increased hip extension displayed by females further supporting their use of the momentum strategy. At toe-off pelvis transverse rotation for females (SDC1) was further towards the right, which is a likely consequence of increased hip extension at toe-off, and contributed to the reduced hip external rotation. An increase in hip internal rotation appeared to have resulted from an increased internal rotation of the thigh

relative to the pelvis (SDC1) which orientated the thigh closer to the intended direction of the kick.

It was observed that the direction of motion was less consistent for females for hip abduction and transverse rotation, due to the relative motion of the pelvis (SDC1). Differences in the current study were not related to pelvic width as this was similar for both sexes. It is possible that pelvis and hip joint musculature in females contributed to this variation, resulting in less stable or controlled frontal plane motion. Weaker hip abductor strength in the non-dominant compared to dominant limb of female footballers could affect the ability to control the upward tilt of the pelvis on the contralateral side during a kick with the dominant limb (Brophy et al., 2009).

Investigating strength and muscle activation of pelvis and hip joint musculature could inform training programmes that may improve lofted instep kick performance in female footballers, as strength and kick coordination training have improved kick performance in maximal low instep kicking (Manolopoulos, Papadopoulos, & Kellis, 2006).

Historically the coaching literature has suggested leaning backwards (Hargreaves, 1990; Hughes, 1994) and away from the ball (Hargreaves, 1990), however the current study suggests the trunk should be moving anteriorly and tilted towards the ball approaching impact (SDC1). Despite an increased thoracolumbar spine adduction at toe-off, point of maximum and impact being associated with increased ball velocity both sexes were tilting the thorax towards the ball approaching impact. However, a more sudden increase towards peak thoracolumbar spine adduction was representative of females (SDC1) possibly to counter-balance the upper body against the kicking limb, followed by a more rapid decrease in adduction towards impact brought about by pelvis motion. It is possible that the reduced adduction movement strategy adopted by the male footballers is preferable.

Both male and female footballers the ankles remained plantar flexed the entire kick. However the female footballers demonstrated interplay between dorsi and plantar flexion motion during

the kick (SDC1) with significantly lower plantar flexion at impact (Table 1), and indicated by the PCA (Table 2). The female footballers may have dorsi-flexed the ankle in preparation for impact in order to achieve optimal foot position on the ball, or a result of less relative muscle strength (Jan et al., 2005) available to control and stabilise the ankle.

As in previous studies on low instep kicking (Barfield et al., 2002; Lees & Nolan, 2002) the mean foot velocity was lower than the mean ball velocity, (Lees & Nolan, 1998) indicating other factors associated with impact are important in generating ball velocity. These include the effective striking mass of the leg and firmness of the foot at impact (Bull Anderson, Dorge, & Thomsen, 1999). Appropriate coaching to stress the importance of a firm ankle and optimal point of foot-ball contact, and strengthening of lower limb muscles to improve firmness of impact may be important to optimise ball velocity in lofted instep kicking for female footballers in particular.

It is acknowledged that there were limitations to the current study. As the kicking task was standardised, a 35m kick was near maximal for females but not for males and therefore further study will identify whether similar strategies are adopted by male footballers performing a maximal distance lofted instep kick. Future studies using a standardised kicking task could conduct maximal distance kicks for the cohort in an unconstrained environment and report the percentage of maximal distance kick the standardised task represents. The study attempted to control for conducting the study in a sports hall rather than on a football pitch by allowing participants to attend familiarisation sessions and undertake as many practice kicks as they felt they needed before data collection. Further research should aim to study a lofted instep kick in a more realistic football environment with players wearing studded football boots.

Available technology was limited to 50Hz cameras. Although previous studies on fast sporting movements have used a similar sample frequency (Johnson & Buckley, 2001; Lloyd, Alderson,

& Elliott, 2000), the accuracy of some data would be improved with high speed cameras; however this is most likely to affect the more rapid phase of the kick approaching impact. As a result of the sampling rate used combined with inherent issues of smoothing through impact, this limited the inclusion of velocity data. Only pre impact 5th metatarsal and post impact ball velocity was subsequently used. It is anticipated that due to advances in technology future work will be able to examine the kick using high speed cameras in an outdoor football environment.

The authors also acknowledge that the low sample size limits the statistical power for comparison of kinematic variables between sexes where differences demonstrate a small effect size. Therefore caution must be exercised when extrapolating the findings to the wider population. However, as there is limited existing research on lofted instep kicking for female footballers the data provided gives researchers a previously unavailable insight into lofted instep kick kinematics and parameters that are likely to be important to inform future research for both sexes. As such it can be considered an appropriate first step for applied research (Bishop, 2008) on lofted instep kicking.

Conclusion

Differences in movement patterns between sexes were observed and there was increased variation in the direction of motion for pelvis obliquity, hip joint and thoracolumbar spine abduction / adduction, thorax and hip joint transverse rotation and ankle dorsi / plantar flexion, when performing a lofted instep kick. Increased hip extension by females during the final step suggested they adopted a momentum strategy, to impart force to the ball during lofted instep kicking. Additionally the development of a tension arc appeared to be another approach used by female players attempting to achieve a 35 m lofted instep kick. Increased hip abduction and reduced plantar flexion of the kicking limb at impact by female players are likely to affect foot and ball impact characteristics and thus be detrimental to performance. The current study suggests that anthropometric, strength or muscle activation differences may be responsible for

variations between the sexes. Future research should further explore the mechanisms behind the differences reported, with a focus on the trunk, pelvis and hip joint musculature. This study also reported the thorax as moving anteriorly and towards the ball in the frontal plane approaching impact. Therefore suggesting coaching points to lean backwards and away from the ball during lofted instep kicking should be reconsidered.

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Table 1: Kinematic and statistical data for variables significantly different between sexes.

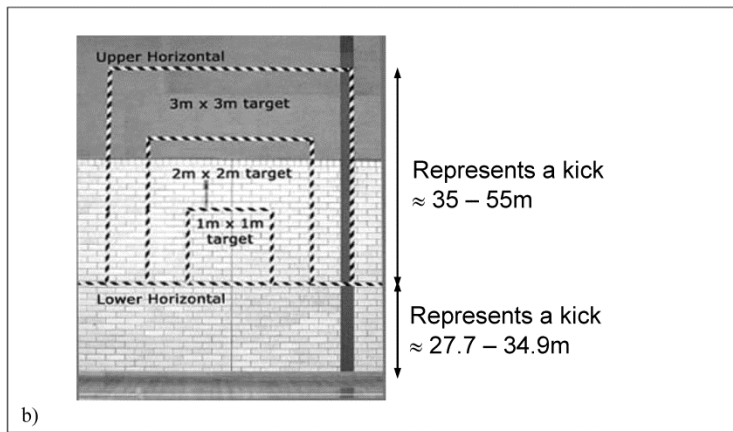
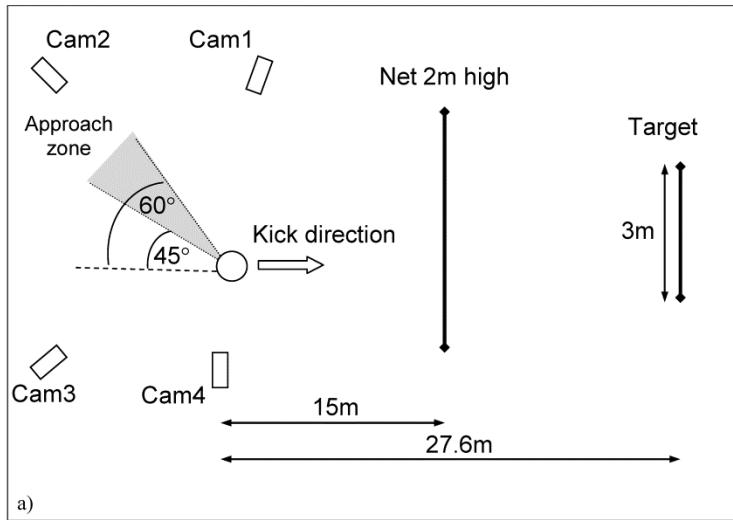
Table 2: Loadings of the angular displacement variables on the two components extracted from the Principal Component Analysis. Component loadings $>|.50|$ have been emboldened for clarity.

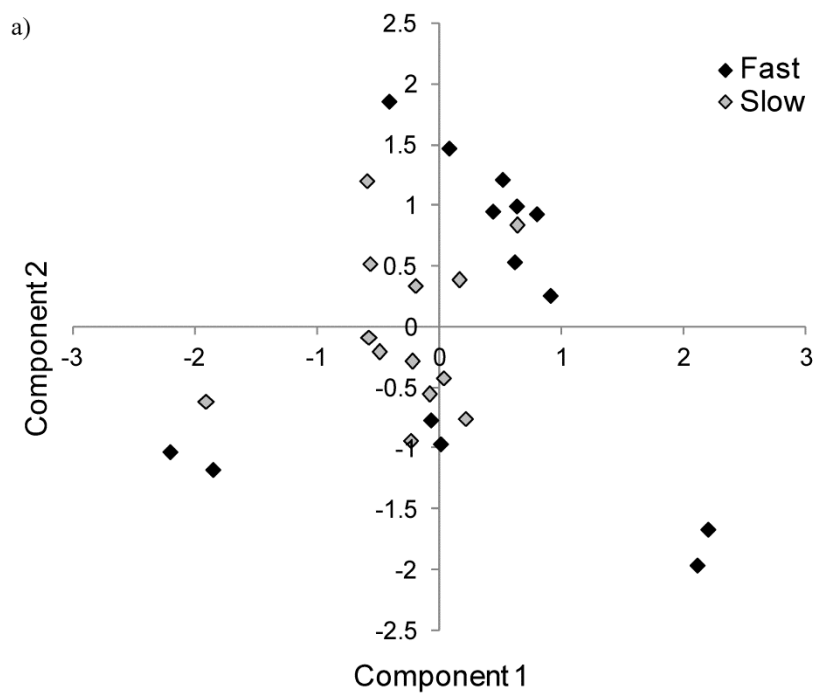
Figure 1: Experimental set-up (a) and details of target (b).

Figure 2: Ordination plots of the first two components overlaid by ball velocity (a) and sex (b).

Variable	Mean \pm s		<i>t</i> (11)	<i>P</i>	<i>d</i>	95% CI (Δd)		Achieved Power
	Male	Female				Lower	Upper	
Peak hip extension (°)	-24.7 \pm 6.8	-32.1 \pm 1.7	-2.784	.018	1.55	0.30	2.97	0.81
Hip abduction at impact (°)	15.7 \pm 7.4	25.5 \pm 7.0	2.453	.032	1.37	0.16	2.79	0.75
Ankle plantar flexion at impact (°)	-28.8 \pm 6.4	-20.5 \pm 5.6	2.496	.030	1.39	0.17	2.60	0.76
Resultant ball velocity (m·s ⁻¹)	23.9 \pm 3.0	18.8 \pm 1.9	-3.648	.004	2.03	0.69	3.37	0.96

Variable	Axis % s²	1 28.30	2 16.84
Hip extension at toe-off		.640	-.149
Hip external rotation at toe-off		.666	.400
Thoracolumbar spine external rotation at toe-off (thorax to L, pelvis to R)		-.546	-.436
Hip extension at heel-strike		.708	-.341
Hip external rotation at heel-strike		.720	.460
Thoracolumbar spine extension at heel-strike		-.558	.371
Thoracolumbar spine external rotation at heel-strike (thorax to L, pelvis to R)		-.601	.052
Hip abduction at impact		-.785	-.159
Hip internal rotation at impact		.705	-.160
Thoracolumbar spine adduction at impact		.764	.288
Peak hip abduction		-.743	-.048
Peak hip internal rotation		.779	.020
Peak hip extension		.687	-.431
Peak hip external rotation		.758	.232
Peak thoracolumbar spine extension		-.540	.356
Minimum thoracolumbar spine adduction (thorax up on R, pelvis down on R)		.776	.363
Maximum thoracolumbar spine adduction (thorax up on R, pelvis down on R)		.587	.470
Peak thoracolumbar spine external rotation (thorax to L, pelvis to R)		-.659	-.143
Ankle plantar flexion at toe-off		-.063	.565
Thoracolumbar spine adduction at heel-strike		.334	.705
Knee flexion at heel-strike		-.094	.748
Ankle plantar flexion at heel-strike		-.340	.665
Ankle plantar flexion at impact		-.363	.571
Peak knee flexion		-.321	.562
Minimum ankle plantar flexion		-.407	.598
Maximum ankle plantar flexion		-.121	.783





SUPPLEMENTAL DIGITAL CONTENT 1

Kinematic description of a 35m plus lofted instep kick for male and female footballers

Lofted instep kicks are typically used to propel the ball long distances during a game of football in order to pass the ball over opposition players or have a shot on goal. Despite being an integral part of the game of football the movement pattern of players performing this skill has not been previously quantified.

Kinematic data has been reported below for a two step, right foot, long lofted instep kick for male and female skilled amateur football players. Time normalised, ensemble averaged data for lofted instep kicks of 35m plus were used to provide a detailed kinematic description of the lofted instep kick, for both segments and joints for males and females. Timing of peak angular displacements were reported as a percentage of total kick time.

Temporal Characteristics

Mean total kick times from final toe-off of the kicking limb prior to impact until foot-ball impact for a 35m plus lofted instep kick were similar for male (0.22 ± 0.02 s) and female (0.22 ± 0.03 s) footballers. The final step of the kick can be divided into an airborne (toe-off to heel-strike) and ground contact phase (heel-strike to impact). Mean values for male footballers indicated they spent 0.09 ± 0.02 s ($43.5 \pm 7.1\%$ of total kick time) in the airborne phase compared to 0.11 ± 0.02 s ($49.4 \pm 6.1\%$) for female footballers. Mean values during the ground contact phase were 0.12 ± 0.01 s ($56.5 \pm 7.1\%$) for male and 0.11 ± 0.02 s ($50.6 \pm 6.1\%$) for female footballers.

Ball and Foot Velocity

Mean resultant post impact ball velocity for a 35m plus kick was $23.85 \pm 3.02\text{m}\cdot\text{s}^{-1}$ and $20.28 \pm 1.20\text{m}\cdot\text{s}^{-1}$ for male and female footballers respectively. Pre impact resultant foot velocity

was $16.37 \pm 1.04 \text{m}\cdot\text{s}^{-1}$ and $15.77 \pm 0.37 \text{m}\cdot\text{s}^{-1}$ for male and female players respectively.

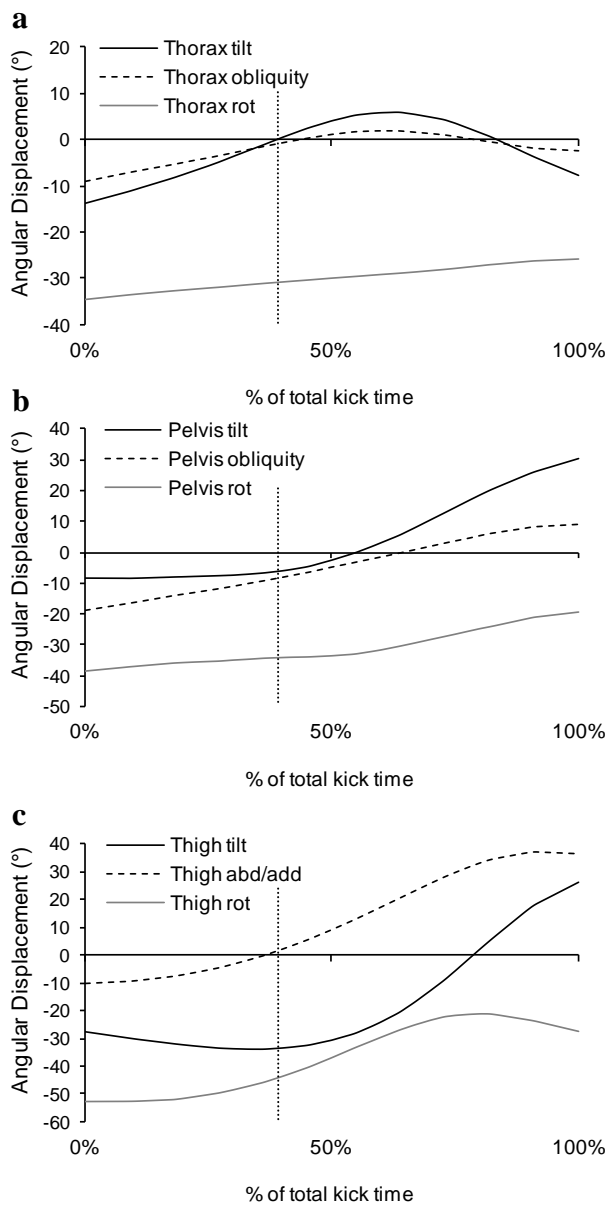
Differences between mean values of male and female footballers were smaller for foot velocity than ball velocity indicating that the characteristics of the ball-foot interaction may affect resultant ball velocity.

Angular Displacement Data

Time normalised, ensemble averaged angular displacement patterns for a 35m lofted instep kick for male and female footballers were derived. Three-dimensional data for the thoracolumbar spine and right hip in addition to thoracic, pelvic and right thigh segments were reported along with two dimensional (sagittal plane) descriptions of the right knee and ankle. Timing of peak angular displacements were reported as a percentage of total kick time.

Thoracic Segment (See Figure S1 a & d): At toe-off the thoracic segment was tilted anteriorly, it then moved posteriorly so it was orientated slightly backwards at heel-strike and reached its maximum backward orientation (Male(M)= $7.0 \pm 5.5^\circ$ at $58.9 \pm 7.5\%$ of total kick time; Female(F)= $7.5 \pm 6.5^\circ$ at $62.0 \pm 3.2\%$ of total kick time) just after. The thoracic segment then moved forward till impact. The thoracic segment was tilted left side up at toe-off, it then tilted downwards on the left side until just after heel-strike (M= $3.0 \pm 5.5^\circ$ at $64.9 \pm 10.1\%$; F= $3.0 \pm 9.0^\circ$ at $62.1 \pm 16.8\%$), and then moved slightly downwards on right side until impact. The thoracic segment was at its maximally externally transverse rotated (towards the right) at toe-off, for both males ($-35.5 \pm 8.5^\circ$) and females ($-34.0 \pm 9.0^\circ$). The thoracic segment then rotated towards the left with females reaching a point of minimum external rotation to the right earlier than the male footballers (F= $-24.5 \pm 8.0^\circ$ at $53.3 \pm 13.5\%$; M= $-25.5 \pm 9.5^\circ$ at $92.3 \pm 11.2\%$). From this point the thorax changed direction and rotated towards the right until impact.

Male



Female

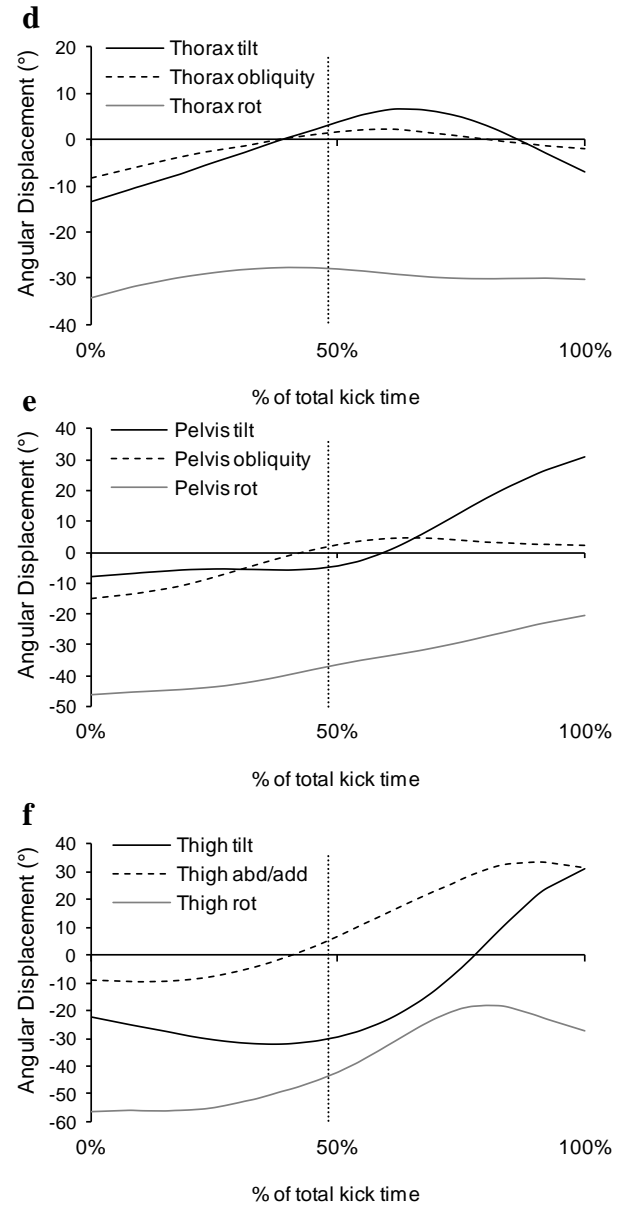


Figure S1: Mean angular displacement (°) of the thoracic, pelvic and right thigh segments during a 35m plus lofted instep kick for male (a-c) and female (d-f) footballers. Positive values for each segment represent: thoracic segment - posterior tilt, right side up tilt and rotation towards left; pelvic segment – posterior tilt, right side up tilt, rotation towards left; right thigh segment – backward tilt, abduction, internal rotation towards left. Dotted vertical lines indicate approximate point of heel-strike. Confidence intervals have been removed for clarity.

Pelvic Segment (See Figure S1 b & e): At toe-off the pelvic segment was tilted anteriorly ($M=-8.5 \pm 6.5^\circ$; $F=-8.0 \pm 2.0^\circ$), it then moved in a posterior direction with an orientation of $-5.5 \pm 7.0^\circ$ and $-4.0 \pm 3.0^\circ$ at heel-strike for male and female footballers respectively. After heel-strike the pelvic segment continued to tilt posteriorly so that it was positioned with a maximum posterior orientation angle of $24.5 \pm 14.5^\circ$ (male) and $31.0 \pm 9.0^\circ$ (female) at impact. Pelvic obliquity (side-to-side) differed between male and female footballers. At toe-off, the pelvic segment was tilted left side up, for both sexes and then moved downwards on the left side. The female footballers reached a point of maximum right side up tilt earlier than the males ($F=7.0 \pm 8.0^\circ$ at $70.1 \pm 19.3\%$; $M=10.5 \pm 3.5^\circ$ at $92.4 \pm 9.7\%$). The movement was then downwards on the right side until impact ($F=2.5 \pm 11.5^\circ$; $M=8.5 \pm 5.5^\circ$). Pelvic segment transverse rotation at toe-off was towards the right ($M=-38.5 \pm 9.5^\circ$; $F=-46.0 \pm 2.5^\circ$), it then transversely rotated towards the left until impact. Male footballers displayed a slightly more marked movement than females in the latter half of the kick, which decreased immediately prior to impact ($M=-22.5 \pm 12.0^\circ$; $F=-20.5 \pm 9.0^\circ$).

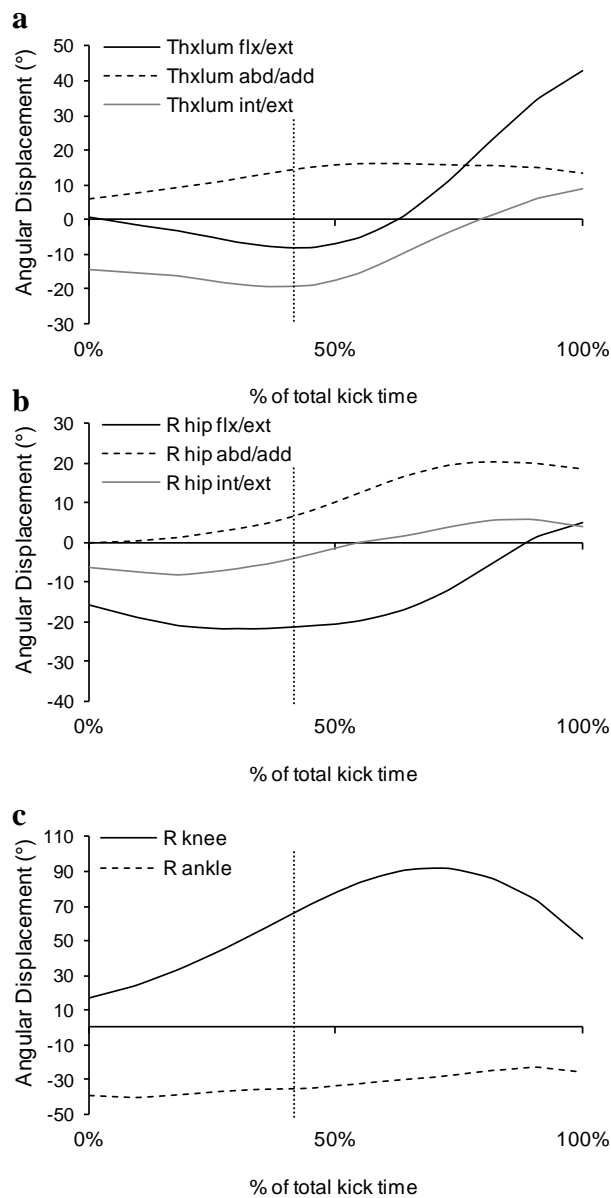
Thigh Segment (Figure S1 c & f): With respect to anterior / posterior tilt, at toe-off, the thigh segment was tilted forward (superior thigh rotated forward of inferior thigh), $M=-27.5 \pm 6.5^\circ$, $F=-22.5 \pm 1.0^\circ$. The inferior thigh rotated backwards reaching its peak forward tilt ($M=-35.0 \pm 4.5^\circ$ at $32.0 \pm 9.5\%$; $F=-32.5 \pm 1.5^\circ$ at $34.1 \pm 6.9\%$) just before heel-strike ($M=-32.5 \pm 3.5^\circ$; $F=-29.5 \pm 4.5^\circ$); it then rotated forward until impact, ($M=16.5 \pm 23.0^\circ$; $F=31.0 \pm 9.5^\circ$). At toe-off, the thigh segment was adducted, it then abducted, reaching a point of maximum abduction just before impact ($M=37.5 \pm 5.0^\circ$ at $92.3 \pm 4.6\%$; $F=34.5 \pm 4.0^\circ$ at $91.9 \pm 4.7\%$), overall a slight adduction movement seemed to occur until impact ($M=31.5 \pm 13.5^\circ$, $F=31.5 \pm 2.5^\circ$). The thigh remained externally transverse rotated throughout the whole kick. After toe-off ($M=-52.5 \pm 4.5^\circ$; $F=-56.5 \pm 4.0^\circ$), the thigh rotated internally until it reached its minimum

externally rotated position ($M=-20.5 \pm 5.5^\circ$ at $79.6 \pm 6.8\%$; $F=-17.5 \pm 10.0^\circ$ at $81.6 \pm 4.7\%$).

The thigh segment then rotated externally until impact ($M=-29.5 \pm 8.0^\circ$; $F=-27.5 \pm 12.9^\circ$).

Thoracolumbar Spine (Figure S2 a & d): At toe-off, the thoracolumbar spine was near neutral with respect to flexion-extension ($M=1.0 \pm 11.5^\circ$; $F=7.5 \pm 14.5^\circ$); it then extended, reaching its maximum orientation just prior to heel strike ($M=-11.0 \pm 14.5^\circ$ at $41.2 \pm 12.7\%$; $F=-5.0 \pm 9.5^\circ$ at $42.2 \pm 14.6\%$). The thoracolumbar spine then flexed and continued to do so until impact ($M=36.5 \pm 21.5^\circ$; $F=40.5 \pm 8.0^\circ$). Differences in thoracolumbar spine movement patterns between male and female footballers were observed during abduction / adduction. Both sexes remained adducted throughout the whole movement although female footballers reached a point of maximum adduction, where the thorax was tilted up on right and pelvis down on right ($M=19.5 \pm 9.5^\circ$ at $74.8 \pm 13.5\%$; $F=18.0 \pm 7.0^\circ$ at $53.3 \pm 5.6\%$) earlier than males. For thoracolumbar spine rotation, although the movement patterns were similar, there were some apparent differences in magnitude of angular displacement between sexes. At toe-off, thoracolumbar spine rotation (thorax to left, pelvis to right) appeared greater for females ($-17.5 \pm 4.5^\circ$) than males ($-14.5 \pm 8.0^\circ$). After toe-off, the thorax continued to rotate towards the left relative to the pelvis reaching its maximum orientation around time of heel-strike for both sexes ($M= -20.5 \pm 10.5^\circ$ at $33.3 \pm 12.0\%$ me; $F=-24.0 \pm 9.5^\circ$ at $24.6 \pm 21.3\%$). The thoracolumbar spine then rotated in the opposite direction until impact ($M=3.5 \pm 13.0^\circ$; $F=11.0 \pm 11.0^\circ$).

Male



Female

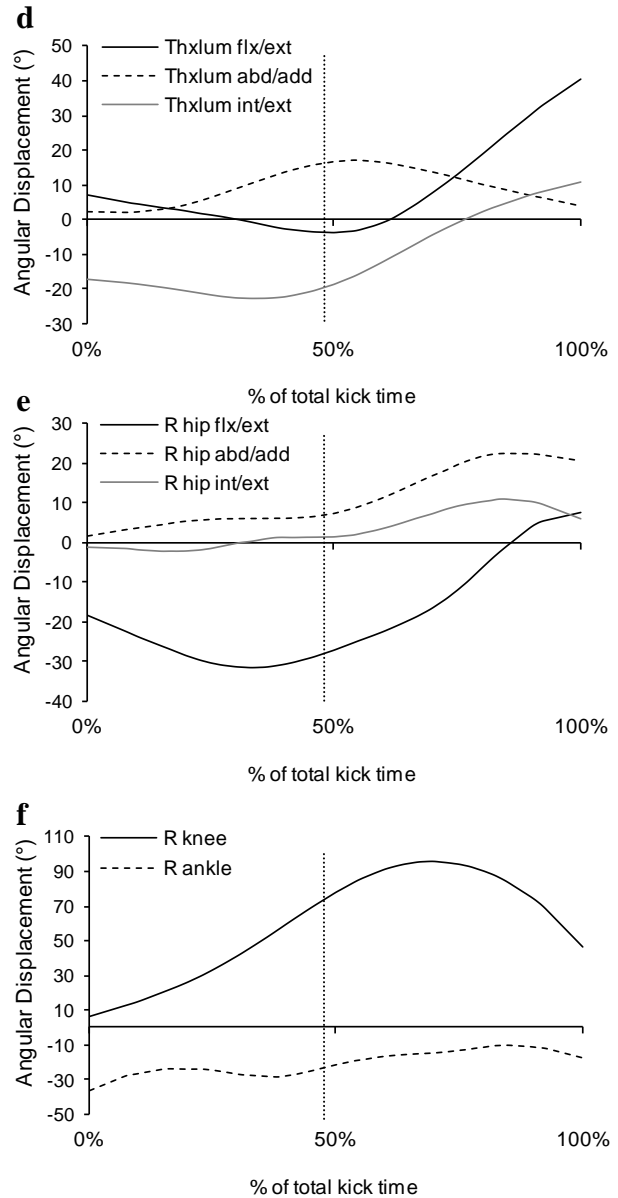


Figure S2: Mean angular displacement (°) of the thoracolumbar spine, right hip, knee and ankle joints during a 35m plus lofted instep kick for male (a-c) and female (d-f) footballers. Positive values for each joint represent: thoracolumbar spine – flexion, adduction (thoracic segment rotated up on right and pelvic segment rotated down on right), internal rotation (thoracic segment rotating to right and pelvic segment rotating to left); right hip – flexion, abduction, internal rotation (thigh segment rotating to left and pelvic segment rotating to right); knee joint – flexion; ankle joint – dorsi flexion. Dotted vertical lines indicate approximate point of heel-strike. Confidence intervals have been removed for clarity.

Hip Joint (Figure S2 b & e): At toe-off, the hip was extended for male and female footballers ($M=-15.5 \pm 8.0^\circ$; $F=-18.5 \pm 3.0^\circ$). The hip then continued to extend until point of maximum ($M=-24.5 \pm 7.0^\circ$ at $33.2 \pm 9.0\%$; $F=-32.5 \pm 2.0^\circ$ at $30.3 \pm 4.2\%$), where female footballers appeared to a larger extension value than the male players. From here the hip started to flex towards heel-strike where the females again exhibited more hip extension than males ($M=-20.0 \pm 11.5^\circ$; $F=-28.0 \pm 5.0^\circ$) and continued to flex until impact ($M=0.0 \pm 12.0^\circ$; $F=7.5 \pm 8.0^\circ$). Hip joint abduction / adduction and internal / external rotation movement patterns were similar, although there were fluctuations in the direction of the movement patterns displayed by females which not evident for males. After toe-off, for male footballers the hip abducted, reaching its peak just before impact ($22.5 \pm 7.5^\circ$ at $84.9 \pm 10.4\%$). The females also reached their maximum abduction just before impact ($24.0 \pm 5.0^\circ$ at $86.8 \pm 6.8\%$) although there was slightly more variability in the direction of the movement pattern up to this point. For hip rotation, after toe-off both sexes moved from maximum external rotation ($M=-9.5 \pm 8.5^\circ$ at $19.4 \pm 16.4\%$; $F=-7.5 \pm 6.5^\circ$ at $34.1 \pm 16.0\%$) to maximum internal rotation just before impact ($M=8.5 \pm 11.0^\circ$ at $79.7 \pm 10.5\%$; $F=14.5 \pm 4.0^\circ$ at $74.6 \pm 17.6\%$). Again the female footballers displayed more variability in the movement's direction. Immediately prior to impact the hip externally rotated ($M=4.5 \pm 11.5^\circ$; $F=6.0 \pm 8.5^\circ$).

Knee and Ankle Joints (Figure S2 c & f): At toe-off, the knee was flexed ($M=16.5 \pm 7.5^\circ$; $F=6.5 \pm 6.0^\circ$), with the female footballers displaying less knee flexion than the males. From here both sexes displayed similar movement patterns as the knee continued to flex, reaching point of maximum flexion ($M=92.5 \pm 8.0^\circ$ at $69.5 \pm 2.8\%$; $F=97.0 \pm 12.0^\circ$ at $69.2 \pm 4.9\%$) just after heel-strike ($M=68.5 \pm 12.0^\circ$; $F=77.5 \pm 15.0^\circ$). The knee then extended until impact ($M=53.5 \pm 13.5^\circ$; $F=46.5 \pm 14.0^\circ$). For both sexes the ankle was plantar flexed at toe-off ($M=-39.0 \pm 5.5^\circ$; $F=-37.0 \pm 7.0^\circ$) and remained plantar flexed the entire kick. For male

footballers the ankle became slightly more plantar flexed after toe-off and then dorsiflexed through heel-strike ($M=-35.0 \pm 11.5^\circ$) until it reached a point of minimum plantar flexion just before impact ($M=-19.0 \pm 9.0^\circ$ at $88.3 \pm 7.5\%$). The female footballers fluctuated between dorsiflexion and plantar flexion movements from toe-off, through heel-strike ($F=-22.0 \pm 10.5^\circ$) until point of minimum plantar flexion ($F=0.5 \pm 19.0^\circ$ at $77.9 \pm 16.6\%$). The ankle then plantar flexed immediately prior to impact for both sexes ($M=-29.0 \pm 6.5^\circ$; $F=-18.0 \pm 7.5^\circ$).